Cost Optimization of PV-Wind- Battery-Grid Connected hybrid system

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***Abstract*:**

This paper presents details of the technical and economic analysis of hybrid power system with cost minimization. The renewable sources, wind and solar energy are connected with different types of backup and are then compared for their economic feasibility. Here battery, grid & diesel generator are used as a backup with renewable energy sources. Removing the battery reduces the cost of energy and net present cost. Presence of diesel generator increases the fuel cost, transportation cost and gas emission. The grid plays an important role of power backup component in the hybrid system, when the renewable energy resources are not enough to meet the load. The data used for the assessment is calculated by HOMER for the location of Mumbai, Maharashtra. This assessment criteria explain the cost with highest renewable fraction to reduce the emission and fulfil the load demand significantly.

Keywords —*Economic Analysis, Renewable sources and HOMER.*

I. INTRODUCTION

Many countries have made progress in promoting renewables in their energy mix but with various obstacles, hence greater efforts are needed. Some renewable energy technologies are close to becoming commercial and should be the first to be deployed on a massive scale. Reducing their costs will require a combined effort in research and development [10]. India has the fifth-largest power generation portfolio worldwide and the country has transitioned from being the world's seventh-largest energy consumer in 2000 to the fourth-largest one within a decade. This rapid growth of power capacity and subsequent rise in demand can be attributed to several factors such as economic growth, increasing prosperity, growing rate of urbanization, rising per capita energy consumption and widening access to energy in the country. Power generation from renewable sources is on the rise in India, with the share of renewable energy in the country's total energy mix rising from 7.8% in financial year 2008 to 12.3% in financial year 2013. Solar and wind are alternative energy resources which are actively discussed globally now a days where these resources are clean, inexhaustible and environmentally friendly. However, the capital cost of a PV system is very high as compared to conventional energy systems [5]. Substantial research, planning and development are required for this purpose [7]. In India many government programs are enhancing the solar power in replacement of conventional energy supplier by giving 30% subsidy on solar panel to promote the renewable sources. New technologies like smart grid will allow distributed generation of renewable energy become more feasible than before [8][11].

II. DATA COLLECTION

The data has been collected from NASA (surface meteorology and solar energy). The PV solar monthly clearness index, daily radiation data (kwh/m^2/day) and wind average speed m/s is shown in table I.

Table I.

	Solar Energy Radiation Data		Wind Speed
Month	**Clearness Index**	**Daily Radiation (kwh/m^2/day)**	**Average (m/s)**
Jan	0.700	5.320	3.840
Feb	0.730	6.250	4.660
Mar	0.727	7.050	5.100
Apr	0.701	7.380	5.620
May	0.673	7.330	5.670
June	0.516	5.640	5.640
Jul	0.460	5.000	6.460
Aug	0.483	5.120	5.840
Sept	0.569	5.650	4.050
Oct	0.645	5.720	3.480
Nov	0.691	5.380	3.410
Dec	0.688	5.000	3.450

III. SYSTEM COMPONENT

A. Photo Voltaic

The annual solar radiation is around 5 to 7.4 Kwh/m^2/d and the scaled annual average solar radiation is 5.9 Kwh/m^2/d as shown in table 1. It can be noticed that highest solar radiations occur during the month of April and lowest in December. The capacity of PV panel is taken as 120KW. The output power of PV panel is:

$$P_{PV}(t) = \eta_{PV} \times N_{PVP} \times N_{PVS} \times V_{PV} \times I_{PV} \qquad (1)$$

Where η_{PV} is conversion efficiency, N_{PVP} & N_{PVS} is number of PV panel in parallel & series respectively, V_{PV} and I_{PV} is operating voltage & current [1].

B. Wind Turbine

The annual wind speed m/s is around 3.4 to 6.5 m/s and the scaled annual average speed is 4.77 m/s as mentioned in table 1. It can be noticed that highest average wind speed occur during the month of July and lowest in November. The capacity of wind turbine output is taken as (140*3) 420 KW. The wind turbine output is define as:

$$P_m(t) = \frac{1}{2} \times \rho \times A \times (v(t))^3 \times Cp(\lambda, \beta) \qquad (2)$$

Where v(t) average hourly wind speed, ρ is air density, A is the swept area of rotor, Cp is the efficiency of wind turbine, λ is the tip speed ratio of rotor blade tip speed to wind speed and β is the blade pitch angle.

C. Grid

The grid of 40 MW is an auxillairy source whereby it act as a backup to the renewable energy system. The grid also acts like a storage system when renewable energy system produces excess energy. Therefore, the price of electricity bought from the grid and the price of electricity sold to grid is known as feed-in-tariff (FiT). If renewable sources system is producing more electricity than the load needs, the excess electricity can sold back to the grid [4].

D. Load

Load is varied with seasonal and monthly consumption depending on climate. The AC load taken as 400 kwh/day and DC load is 100 kwh/day.

E. Diesel Generator

Diesel generator is used as a back up to the renewable energy system. The capacity of diesel generator is 100KW for the simulation.

IV. ASSESSMENT CRITERIA

The assessment criteria is cost analysis and its effect on the system.

A. Total Net Present cost

The total net present cost of the system is the present value of all the cost that it incurs over a lifetime, minus the present value of all the revenue that it earns over its life time. Various cost include capital cost , replacement costs, operating and maintenance cost, fuel cost, emission penalty and the cost of buying power from the grid. Revenue includes salvage value and grid sales revenue. The following equation to calculate the net present cost.

$$C_{NPC} = \frac{TAC}{CRF} \qquad (3)$$

Where TAC is the total annualized cost and CRF is capital recovery factor [5].

$$\mathrm{CRF} = \frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{N}}}{(1+\mathrm{i})^{\mathrm{N}} - 1} \qquad (4)$$

Where N is the number of years and i is the annual interest rate. Annual interest rate can be calculated using equation.

$$i = \frac{i' - f}{1 + f} \qquad (5)$$

B. Cost of energy

The cost of energy (COE) is defined as:

$$\mathrm{COE} = \frac{\mathrm{TAC}}{\mathrm{E_{prim}} + \mathrm{E_{def}} + \mathrm{E_{grid,sales}}} \qquad (6)$$

Where E_{prim} and E_{def} are the total amount of primary and defferable load respectively, that the system serve per year, $E_{grid,sales}$is theamount of energy sold to the grid per year. The denominator in equation is an expression of the total amount of useful energy that the system produces per year. The cost of energy is therefore the average cost per kwh of useful electrical energy produces by the system.

C. Payback Period

The payback period is an indication of how long it would take to recover the difference in investment cost between the current system and the base case system.

D. Optimal Operation Strategy

Optimal dispatch strategy of hybrid energy system is to find the most economical schedule for different combination of renewable generators with grid, satisfying load balance, resource availability and equipment costraints[2].

$$\Delta P = [(P_s \times N_s) + (P_W \times N_W)] Load\ demand \qquad (7)$$

Where ΔP is the total power generated by hybrid system, N_s and N_w are the total number of solar PV panel and wind turbine respectively, and P_s and P_w are corresponding power generated. If the renewable energy excess after meeting the demand then no grid connection is required, if load exceed the renewable energy output then grid connection require for fulfill demand.
if $\Delta P > 0$, No grid connecttion require.
if $\Delta P < 0$, Grid connection require.

The combination with lowest cost, minimal use of grid electricity and service reliability is selected as the optimal one. The unit sizing for a WT-PV hybrid combination is to minimize the total capital cost C_c given by

$$C_c = \sum_{W=1}^{N_W} C_W + \sum_{S=1}^{N_S} C_S \qquad (8)$$

Where N_w and Ns are the total number of wind and solar PV respectively, and C_W and C_S are the corresponding capital cost. The optimal operation strategy for a different system combination so as to minimize the annual operating cost C_o computed based on the operating cost for the interval t in a day.
For PV/wind/grid is

$$C_{ot} = \sum_{1}^{365} \{ \sum_{t=1}^{24} (C_{OW}(t) + C_{OS}(t) + C_{og}(t))\} \qquad (9)$$

For PV/wind/grid/battery is

$$C_{ot} = \sum_{1}^{365} \left\{ \sum_{t=1}^{24} \left(C_{OW}(t) + C_{OS}(t) + C_{og}(t) + C_{Ob}(t) \right) \right\} \qquad (10)$$

For PV/wind/diesel generator is

$$C_{ot} = \sum_{1}^{365} \{ \sum_{t=1}^{24} (C_{OW}(t) + C_{OS}(t) + C_{od}(t))\} \qquad (11)$$

$C_{ow}(t)$, $C_{os}(t)$, $C_{og}(t)$, $C_{ob}(t)$ and $C_{od}(t)$ are the operational cost of wind turbine, solar panel, grid, battery and diesel generator for the hourly interval t (t = 24-1) respectively. Operational cost are calculated on the basis of component characteristics, size and efficiency.

E. Total Annualized Life Cycle Cost

Total annualized life cycle cost of the system incorporating components of both capital and operating cost.

$C_{an} = (C_c \times CRF + C_{ot})$ (12)

F. Optimization of System Cost

Depending on the area specific criteria and availibility of renewable energy sources, the combination of hybrid power generation can be optimized

G. Renewable Fraction

The renewable fraction is the portion of the system's total energy production originating from renewable power sources. This can be calculated by dividing the total annual renewable power production by the total energy production. As its value increases the system become more and more renewable energy dependent [9]**.** As the load increases size of renewable energy sources is also increases ultimately it increases the cost of hybrid distribution system.

$$\%R.F = \frac{\text{Total annual renewable power production}}{\text{Total annual energy production}} \times 100 \qquad (13)$$

H. Battery

The Lead Acid battery is used having 25 numbers in each string of 12V, so bus voltage is 300V. The capacity of battery is 1250 kWh.

V. METHODOLOGY

The distribution generation unit such as solar and wind are variable energy sources and depend on weather conditions. Therefore it cannot be ensured whether distribution generation will satisfy and meet all operation criteria in the power system without proper backup and economic analysis[6]**.**

Table II. Configuration of Different Hybrid System

Case	**System Configuration**
Case A	PV(120KW) + WT(140*3) + Grid(40 MW)
Case B	PV(120KW) + WT(140*3) + LA Battery(1250KWH) + Grid(40 MW)
Case C	PV(120KW) + WT(140*3) + DIESEL GEN(100KW)

The renewable sources PV and WT are used with different types of back up to reduce cost resulting increased reliability. In table. II three different models has been proposed for study

VI. SIMULATION AND OPTIMIZATION

Modelling, simulation and optimization of the proposed system for each case are shown in fig. 1, 2 and 3.

A. Case A: PV-WT-Grid system

The hybrid power system and their energy supplied to load for case A are shown in fig. 1. (a) and (b) respectively.

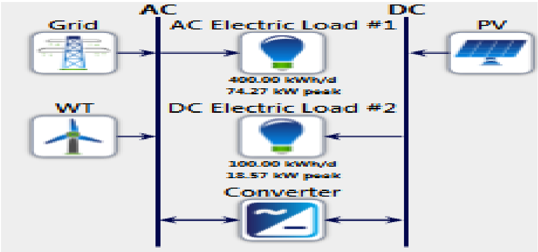

Fig.1(a)Hybrid System of *PV-WT-Grid System*

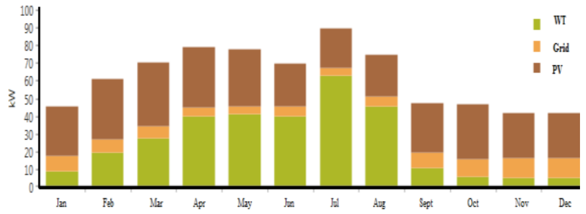

Fig. 1(b) Monthly Enegy Supplied load

B. Case B:PV-WT-Battery-Grid System

The hybrid power system and their energy supplied to load for case B are shown in fig. 2. (a) and (b) respectively.

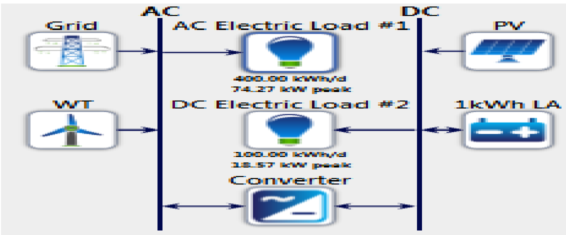

Fig.2(a) Hybrid System of PV-WT-Battery-Grid System

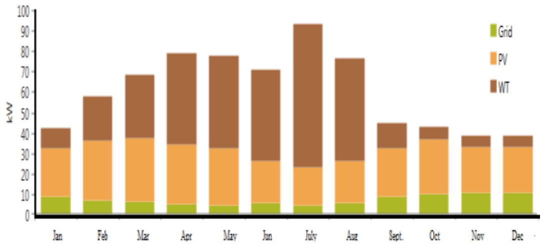

Fig. 2(b) Monthly Enegy Supplied Load

C. Case C:PV-WT-GEN system

The hybrid power system and their energy supplied to load for case A are shown in fig. 3. (a) and (b) respectively.

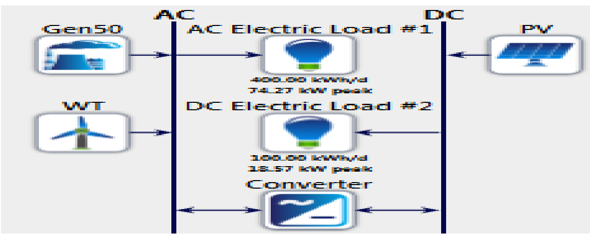

Fig. 3(a) Hybrid System of PV-WT- GEN System

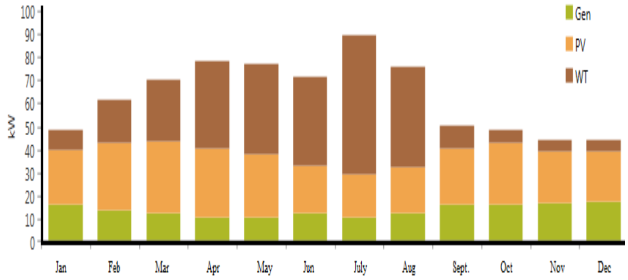

Fig. 3(b) Monthly Enegy Supplied load

VII.RESULT & DISCUSSION

Economic analysis is very important aspect before installing the system to generate power and rank the system according to their net present cost [3].

Table. III : Economic Analysis for all Cases

Case	COE ($)	NPC ($)	OC ($)	IC ($)	O&M ($)	R.F (%)
A	0.57	3757009	46181.2	3160000	16044	87
B	0.69	4579975	80833.3	4579975	28544	87
C	2.07	4884413	129523.1	3210000	41695	36

The economic analysis for Cost of Energy (COE), Net Present Cost (NPC), Operating Cost (OP) Initial Capital (IC) and Operating & Maintenance cost (O&M) as shown in table 3. The COE is least in case A because it is connected with grid as a backup with renewable fraction of 87%. For case B, COE slightly increased from $0.57 to $0.69 due to the presence of battery. In case C, COE is approximately 33% more in comparison with case A and B so the presence of diesel generator increased NPC, OC, O&M with only 36% of renewable fraction. All the major cost of capital, replacement, operating & maintenance, salvage and fuel cost of each component, PV,WT, lead acid battery, DG and grid are compared separately is shown in table 4. Here, grid, LA battery and diesel generator has been used as a backup where grid has least cost amongst all three. For remote location or off grid, battery is better choice than diesel generator as a backup because battery connected hybrid system has less total cost than diesel generator.

Table. IV : Cost Analysis Separately for each Component

	Capital Cost ($)	Rep. Cost ($)	O& M Cost ($)	Salvage Cost ($)	Fuel Cost ($)	Tot. Cost ($)
PV	27,848	-	1,200	-	-	29,048
WT	21,6592	69,051	28,000	38915	-	352558
LA	29,008	25,627	12,500	3,474	-	70609
DG	3,867	13,175	12,882	781	47234	77939
Grid	-	-	13,155	-		13,155

Table. V : Running Cost Analysis for all Cases

Case	Capital cost ($)	Repl. Cost ($)	O&M Cost ($)	Salvage Cost ($)	Fuel cost ($)	Tot. Cost ($)
A	244440	69051	42355	38915	0.0	394761
B	273448	94678	54855	42389	0.0	465370
C	248307	82226	42082	39696	47234	459545

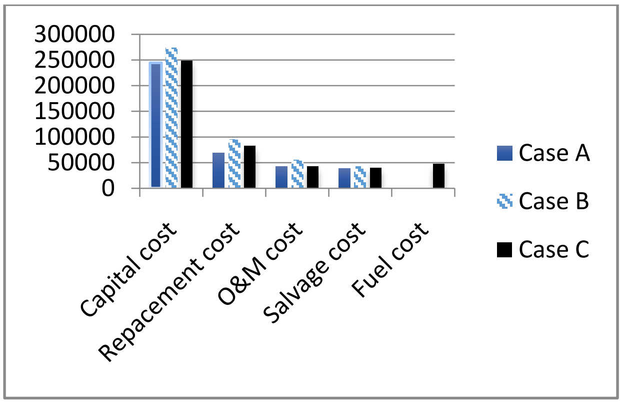

Fig.4. Cost Comparison in Dollar ($)

The detailed simulation result of these three combination regarding yearly electricity production, consumption and amount of grid purchase or sale is shown in table. VI & VII.

Table.VI : Electricity Production in Kwh/year

Case	System Component	Production Kwh / year	% of Production
Case A	PV	251,454	46.27
	WT	226,644	41.71
	Grid Purchase	65,321	12.02
	Total	543,418	100
Case B	PV	215,532	40.41
	WT	254,086	47.64
	Grid Purchase	63,692	11.94
	Battery	-	-
	Total	533,309	100
Case C	PV	215,532	38.87
	WT	121,111	21.84
	Gen	217,788	39.28
	Total	554,430	100

Table. VII : Consumption in Kwh/year

Case	Load	Consumption Kwh/year	% of Consumption
Case A	AC Primary load	146,000	28.5
	DC Primary load	36,500	7.1
	Grid Sale	330,618	64.4
	Total	513,119	100
Case B	AC Primary load	146,000	28.7
	DC Primary load	36,500	7.2
	Grid Sale	326,796	64.2
	Battery	-	-
	Total	509,296	100
Case C	AC Primary load	146,000	80
	DC Primary load	36,500	20
	-	-	
	Total	691796	100

VIII. EMISSION ANALYSIS

The analysis for pollutant gas emission for Case B and C is shown in table VIII.

Table. VIII : Emission Analysis

Quantity	Case B Kg/yr	Case C Kg/yr
Carbon Dioxide	-153030	124,381
Carbon Monoxide	0.00	307.02
Unburned Hydrocarbon	0.00	34.01
Particulate Matter	0.00	23.14
Sulphur dioxide	-663.45	249.78
Nitrogen Oxide	-324.46	2739.5

VII. OPTIMUM SYSTEM CHOICE

For finding optimum hybrid system, electric production and consumption rateshas been compared. On comparison of case A & B, case B is more reliable since it has sufficient storage facility to meet extra or unexpected load demand. If grid fails then case B can give necessary back up and handling the situation becomes easier as compared to case A. In case C excess emission can be observed on usage of diesel generator. Advantage and disadvantages of different hybrid system has been discussed below.

A. Advantages of the Different Hybrid System

1. Case A:

- Reduced operational cost due to no fuel consumption and low PV maintenance.
- Increased operational life due to no use of generator set operating hours.
- Environmentally friendly due to reduced emissions and noise pollution.
- Smooth out seasonal weather fluctuations.

2. Case B:

• Highly reliable and environment friendly.
• Safe, clean and quiet to operate.
• Improved reliability through diversifying power sources and continuous power supply.
• Increased operational life due to no use of generator set operating hours.
• Reduced 'deep-cycling' of batteries and extended battery life.
• Improved energy services.

3. Case C:

• Operate cost-effectively in remote areas and for many applications.
• Flexible and can be expanded at any time to meet demand.
• Increased autonomy – independence from the grid or backup during outages.

B. Disadvantages of hybrid system

• Additional investment cost of renewable energy sources, batteries and power electronics.
• Limited experience of customers and supply utilities with renewable energy and hybrid system technology.
• Systems are generally complex. Life-cycle economic analysis required like detailed system simulation.
• Diesel generator is very expensive to run and produce environmental pollution and noise.

VIII. CONCLUSION

An economic analysis of three different configuration has been presented. HOMER software has been used for simulation and cost optimization analysis. After analysing all the cases, case A found to be most cost effective compared to the others. Diesel generator has several issues such as high cost of fuel, extra transportation cost and negative environmental effect. It is noteworthy that due to low emission of harmful gases, case A and B proved to be beneficial to the environment. If grid power fail, then case B can fulfil load demand very easily because battery can give required backup for emergency load. In spite of high capital cost in case B, it is highly profitable for long run and leads to economic, social and environmental benefits. So renewable sources with existing grid and battery as in case B is the optimum solution in long run and significantly increases greater reliability in power supply.

REFERENCE

[1] V.K. Soni, R. Khare, "Optimal sizing of HRES for small sized institute using HOMER,IEEE 2nd International Conference on Electrical Energy Systems, pp. 77-81,ICEES,-2014.

[2] Shekhar K Pawar, Yogesh Aaher, Ajit C. Chaudhari, Yogesh Jhadhav, "Modeling and simulation of hybrid solar wind grid power generation system for electrification", IEEE international conference on advances in engineering and technology, pp.1-6,ICAET 2014.

[3] Prasenjit Mazumder, Md. Haibul Jamil, C.K. Das, M.A. Matin, "Hybrid energy optimization: an ultimate solution to the power crises of st. Martin Island", Banglades', 9th IEEEInternational forum on strategic technology, pp. 363-368, 21-23 oct, 2014.

[4] Bidisha Roy, Ashok Kumar Basu, Subrata Paul, "Techno-Economic feasibility analysis of a grid connected solar photovoltaic power system for a residential load",pp. 1-5, 2014.

[5] R.N.S.R Mukhtaruddin, H.A. Rahman, H.A. Hassan, "Economic analysis of grid-connected hybrid photovoltaic-eind system in Malaysia", pp. 577-582, 2013.

[6] K. Balachander, S. Kuppusamy, P.Vijayakumar.: "Comparative study of hybrid photovoltaic-fuel cell system/ hybrid wind-fuel cell system for smart grid distributed generation system", IEEE International conference on emerging trends in science, engineering and technology, pp. 462-466, 2012.

[7] Md. Moniruzzaman., Sami ul Hasan, "Cost analysis of PV/wind/diesel/grid connected hybrid system", IEEE International conference on informatics, Electronics and vision -ICIEV, pp. 727-730, 2012.

[8] Rashayi Emanuael, chikuni Edward, "The potential of grid connected photovoltaic arrays in zimbabwe", pp. 285-288, 2012.

[9] Khurshid Hasan, Fatima Kaniz., Md. Sohel mahmood, "Feasibility of Hybrid Power Generation over Wind and Solar Standalone System", 5th International Power Engineering and Optimization Conference (PEOCO2011), Malaysia : pp.1-7,6-7 June, 2012.

[10] Vuc Gheorghe, Borlea Ioan., Constantin Barbulescu., Octavian Prostean, "Optimal energy mix for a grid connected hybrid wind- Photovoltaic generation system", pp. 129-132, 2011.

[11] Aktabujjaman, S. Islam, and M. A. Ullah, "Efficient power system with existing power system", IJEEE, Vol. 3, No. 5, October 2015.